Parameterization of Integrated Aerosol Effects in Marine Stratocumulus Clouds

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LONG-TERM GOALS

The development and improvement of cloud microphysical parameterizations for use in cloud and numerical weather prediction models

OBJECTIVES

Conduct detailed studies of marine stratocumulus cloud microphysical processes in order to achieve a better understanding of interactions between microphysical, radiative and boundary layer thermodynamical processes and to improve their formulation in numerical weather prediction models.

The overall objective is divided into the following tasks:

1) Development of an advanced version of a high-resolution large eddy simulation model with explicit microphysics (SAMEX) that is capable of running on advanced, distributed-parallel computing architectures.

2) Participation in the international GCSS model intercomparison study to investigate the precipitation formation in trade cumulus clouds sampled during the RICO (Rain in Cumulus over the Ocean) field project.

3) Development methods for retrieval of cloud and drizzle parameters for use in initialization of numerical forecast models

APPROACH

The research is based on the CIMMS high-resolution LES model of marine boundary layer stratocumulus clouds with explicit formulation of aerosol and drop size-resolving microphysics. The LES simulations, as well as observations from field projects are used to study drizzle formation in marine stratocumulus. This year we started work to generalize our parameterizations for cumuliform clouds. Simulations of observing systems, like Millimeter Wave Cloud Radar with Doppler capabilities, are used to develop algorithms for retrieval of cloud liquid water and drizzle flux for initialization of boundary layer stratocumulus in mesoscale prediction models.

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WORK COMPLETED

The following tasks have been completed this year:

1. The new version of a high-resolution large eddy simulation model with explicit microphysics (SAMEX) has been developed that is capable of running on advanced, distributed-parallel computing architectures.

2. The new model was employed in the latest GEWEX Cloud System Study (GCSS) model intercomparison of marine trade cumulus. Work started on the analysis of the effect of precipitation on cloud structure and dynamics, as well as on extending our stratocumulus microphysical parameterizations for the shallow convection cloud systems.

3. A model of an observing system simulating millimeter wave cloud radar with Doppler capabilities has been developed and applied for analysis of radar reflectivity and Doppler velocity return signals from stratocumulus clouds with different amounts of precipitation. Based on the analysis we have suggested new methods for retrieval of cloud and drizzle parameters.

RESULTS

1. System for Atmospheric Modeling with Explicit Microphysics -- SAMEX

We completed the transition of the CIMMS LES with explicit microphysics to a new dynamical core capable of running on distributed-parallel computingarchitectures.

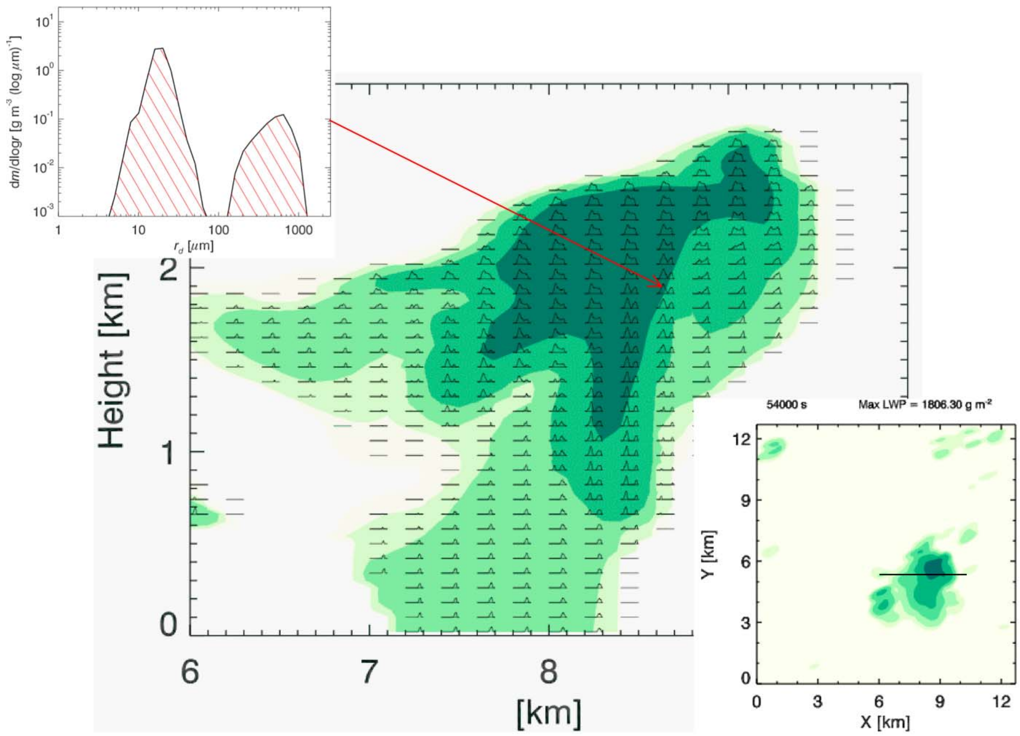

Figure 1. Examples of SAMEX microphysical output during simulation of a precipitating convective cloud system based on data from the RICO field project. The center plot depicts cloud drop spectra in a vertical cross-section through a cloud cell shown in the lower right corner. The plot in the upper left shows zoomed spectra at a spatial point indicated by the red arrow. [graph: the complex dynamics-microphysics interaction is illustrated in this 3 km deep convective cell]

The model dynamical core consists of the System for Atmospheric Modeling (SAM) developed by Prof. Marat Khairoutdinov at New York State University at Stony Brook, formerly a CIMMS/OU PhD student. The similarity of the design and numerics in SAM and the CIMMS LES made this transition quite straightforward.

The new model, called SAMEX, was tested extensively for marine stratocumulus (ASTEX case) and was employed in the latest GEWEX Cloud System Study (GCSS) model intercomparison of marine trade cumulus (Figure 1: in order to avoid cluttering the drop spectra are shown only for every other grid point). Results for the ASTEX and RICO cases compare favorably with the original CIMMS and community LESs.

2. The role of precipitation on large eddy simulations of trade cumulus cloud systems

One of the foci of the RICO (Rain in Cumulus over the Ocean) project was to evaluate the role of precipitation in the dynamics and evolution of the trade cumulus boundary layer. The CIMMS cloud physics group was one of 15 international groups to participate in a model intercomparison to explore whether state of the art LES models are capable of producing the characteristic features of trade

cumulus as sampled during the field project. The CIMMS group was one of only three to employ LES (SAMEX) with a size-resolving microphysical formulation.

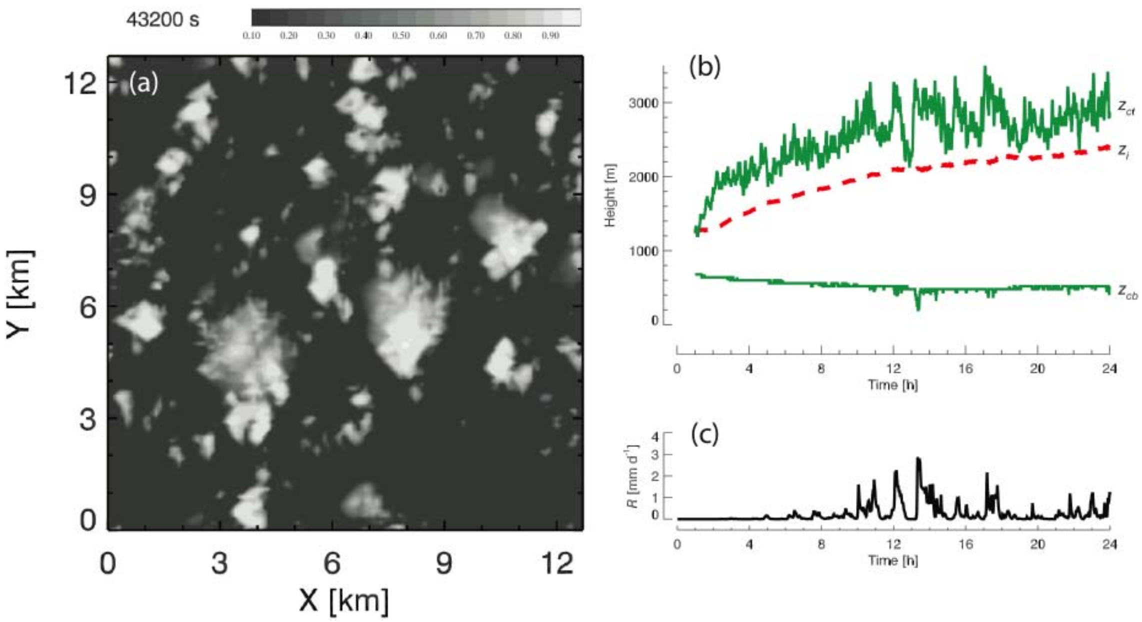

Figure 2. SAMEX results for the RICO trade cumulus intercomparison. (a) Plan view of albedo at 12 h; (b) Evolution of lowest cloud base and highest cloud tops (green), and height of the trade inversion (dashed red); (c) Mean surface precipitation. [graph: cloud fraction and precipitation amounts are well in line with observations]

Preliminary results from the 24 h intercomparison simulation emphasize overall cloud characteristics (Figure 2). Cloud fraction, for example, fluctuates between 0.1 and 0.2, consistent with the snapshot plan view of albedo. Cloud base is largely dictated by surface thermodynamics and remains relatively steady over the course of the simulation, while maximum cloud top is highly variable and closely tied to the life cycle of individual cumulus towers. The inversion height steadily increases, a result of penetrative entrainment from updrafts rising as far as several hundred meters above the inversion and into the free troposphere.

In initial comparisons of simulations with and without precipitation physics, modest amounts of precipitation tend to exert their most pronounced effect in the upper part of the cloud layer, tending to slightly suppress buoyancy and water fluxes, vertical velocity variance, and entrainment. Subsequent analyses will focus on the effect of precipitation on cloud structure and dynamics, as well as on extending our microphysical stratocumulus parameterization for the shallow convection clouds.

3. The characterization of stratocumulus cloud liquid water and precipitation flux using Doppler radar observations

The accuracy of weather model forecasts depends to a signigicant degree on the frequency and fidelity of data available for model initialization. Cloud and weather radars are used extensively to retrieve such data, especially, cloud microphysical parameters.

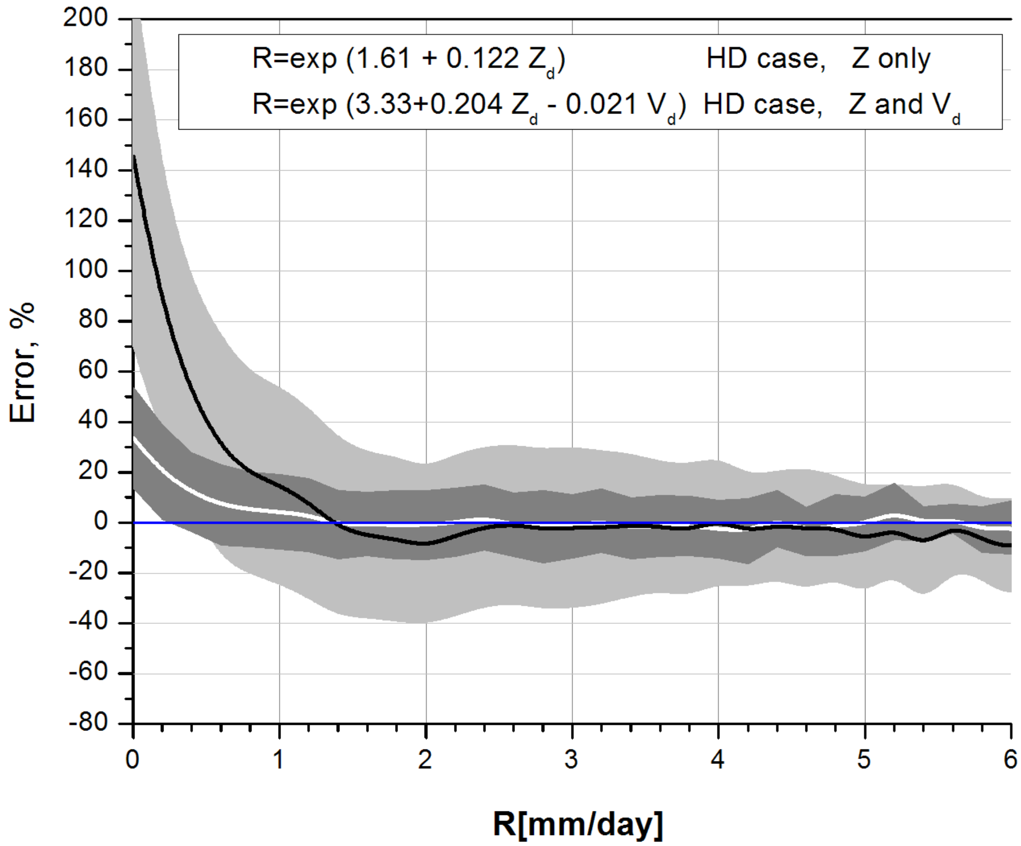

Figure 3. The errors of drizzle flux retrieval for the heavy drizzle case. The black and white lines are the one (1P) and two-parameter (2P) retrieval mean errors; the shading areas represent the mean plus/minus one standard deviation. Light/dark gray shading corresponds to the 1P and 2P retrievals, respectively. [graph: Accuracy of the drizzle retrieval is substantially improved with the inclusion of Doppler velocity parameter]

We evaluate the errors of microphysical retrievals based on radar reflectivity, mean Doppler velocity, and Doppler spectrum width using the controlled framework of the Observing System Simulation Experiments (OSSEs). Cloud radar parameters are obtained from drop size distributions generated by the high-resolution CIMMS LES model with explicit microphysics. We show that in drizzling stratocumuli the accuracy of cloud liquid water (Q_l) retrieval can be substantially increased when information on Doppler velocity or Doppler spectrum width is included in addition to radar reflectivity. In the moderate drizzle case (drizzle rate R of about 1 mm/d) the mean and standard deviation of errors is of the order of 10% for Q_l values larger than 0.2 g m^{-3}; in stratocumulus with heavy drizzle (R > 2 mm/d) these values are approximately 20-30%. Similarly, employing Doppler radar parameters significantly improves the accuracy of drizzle flux retrieval (Figure 3). The use of Doppler spectrum width instead of Doppler velocity yields about the same accuracy, thus demonstrating that both Doppler parameters have approximately the same potential for improving microphysical retrievals. We note that our error estimates represent the theoretical lower bound on retrieval errors, because the actual errors will inevitably increase, first and foremost, due to uncertainties in estimation contributions from air turbulence.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will lead to more accurate numerical weather predictions for Navy operations. The new retrieval algorithms of cloud and drizzle parameters will allow more accurate initialization of weather forecast models.

TRANSITIONS

Our results have been reported at six scientific meetings, published in two major refereed journals and conference proceedings (9 papers) and, thus, are known to the scientific community.

RELATED PROJECTS

The study is aimed at development of physical parameterizations for cloud and regional scale models. It is related to the ONR project "Improvement of the cloud physics formulation in the US Navy Coupled Ocean-Atmosphere Modeling Prediction System (COAMPS)" which goal is to develop and implement physical parameterizations into mesoscale prediction models in general, and COAMPS in particular.

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